Oral Presentation at PPEPPD on May 20-25, 2001

Development of fuel cell technology has mostly been undertaken under the national program in Japan, as you know, named as the New Sunshine Program of METI(Ministry of Economy, Trade, and Indusrry) NEDO is responsible for the coordination of this project. Table outlines the fuel cell development program initiated by NEDO. First of all, NEDO has launched the development on PAFC in 1981 and MCFC in 1984 under the sponsorship of the Agency of Industrial Science and Technology, former MITI. As to PAFC, the research and development stage is completed and now under the phase of practical test by users.

In contrast, MCFC has been under the demonstration phase based on the experimental operation of relatively large capacity units as high as several hundreds kW scale.

The research and development activities on SOFC and PEFC were launched in 1989 and 1992 respectively. Of course many Japanese industrial companies have been promoting all kinds of fuel cells independently of this NEDO project.

Next I would like to show you the overall view of RD&D on each kind of fuel cells in Japan.

PAFC

PAFC is now coming up into the commercially viable stage after a lot of experiences of long demonstration operations.

Many PAFC co-generation power plants have been installed in the past decades in urban area facilities such as factories, hotels, hospitals, condominiums, and office buildings. These results show for PAFC to be satisfactory in its performances, but that is not yet in the stage of fully commercialization, we call it semi-commercial state, because of its high cost. The price is now assumed to be 400,000 yen/kW or US$3,000/kW. This price is too high to be fully commercially viable.

With a recently growing interests in resource recycling, the effective use of fuel cell is expected not only as a conventional co-generation system that uses fossil fuels, but also as a key technology to circulate resources. From this point of view, a fuel cell system using biogas is proposed. In the disposal of waste such as sewerage sludge, livestock excrement, food waste drain, and garbage, the methane anaerobic fermentation of organic waste has been developed. The methane-rich gas generated in this process shows at least the composition of 60%vol.methane, 40%vol.carbon dioxide, and very small quantity ingredients of sulfides, halogen compounds and ammonia.

A typical example of the whole system, which consists of 200kW PAFC plant and such bioprocess as that above mentioned, is proposed. With approximately 80Nm3/h of biogas, 200kW of electric power can be obtained. Heat flow of 176,000kcal/h can also be used for heating within the bioprocess or as supply heat for heat-consuming units in the facility. A pretreatment unit should be added upstream to the fuel cell plant in order to eliminate ingredients such as sulfides, chloride, and ammonia.

The practical operation of this system has been continued since fiscal year 1997 by a joint project between the Bureau of Sewerage in Yokohama City and Toshiba.

MCFC

MCFC is so suitable for large scale and high efficient electric power generation with combined cycle, because of its operation temperature as high as 600? . Then MCFC plant is supposed to be fit for electric utility use.

MCFC Research Association constructed and had been operating a 1,000kW Power Plant in the Kawagoe Thermal Power Plant, Chubu Electric Power Company Inc. This plant consists of four units of external reforming 250 kW class stack, and is designed to obtain an efficiency of 45% in the base of HHV. These stacks were fabricated by Hitachi, Ltd. and IHI Co.,Ltd. The 250kW stack of IHI, for example, consists of two 125kW substacks, each of which is composed of 140 cell layers of $1m^2$. Along with developing these stacks for 1 MW plant, Hitachi and IHI designed and fabricated respectively the fuel reforming system and the plant control system.

This project had been continued until the end of January 2000 after 5 years since the start in October 1995, and its operation test was also completed. The power generation had just started on August 4 1999, and reached at the rated output of 1,000kW in electricity on November 5 1999. Tab. 2 shows results compared with the target of development. Although the operation hours fell short of its target because of the time limit to end the project within FY 1999, the other items in the target were sufficiently cleared.

The Kansai Electric Power Company and Mitsubishi Electric Corporation had carried out an operation of internal reforming 200kW class stack as another part of MCFC Research Association Project. The power generation test was completed in February 2000 after the operation time of 5,259 hours with successful achievement of all the development targets. The initial average cell voltage of 0.837V under the current density of 150mA/cm2, and the stack decay rate of 0.4%/1,000hours were observed.

SOFC

Electric Power Development Co. and MHI are operating the pressurized 10kW class SOFC modules of a segmented type tubular structure. This plant has already been operated for 7,000 hours, and so far a voltage decay rate of only 1 to 2% was confirmed. They also fabricated 1kW module with electrodes, electrolytes, and inter-connector, all of which was made by print method for reducing the production cost. This module has been tested for 2,000 hours.

TOTO, Kyushu Electric Power Co. and Nippon Steel Corporation are making a tubular vertical striped SOFC cell by using a wet method which is suitable for a mass production. The initial performance and durability were evaluated for a single cell. As for the performance with methane gas as fuel, the power density was 0.204 W/cm2 at the fuel utilization of 70%. The degradation rate for the long term generation test was fairly low.

This cell is 2.2 cm in diameter and 70 cm in effective length. The durability and reliability of the cell were verified in several kW class level with anticipation of swift realization. For example, the durability of a hydrogen-fueled single cell was evaluated under an operational temperature of 900?, and a voltage drop of 0.3%/1,000hrs with a current density of 0.3A/cm2 for 2,000 hours was confirmed. The characteristics of the cell have been continuously improved, and the output density of 0.18W/cm2 has been measured under the fuel utilization rate of 80% in a single cell.

Chubu Electric Power Co. and Mitsubishi Heavy Industries(MHI) are developing a unique shaped planar type of SOFC cell which is called MOLB type. In order to improve the reliability, they modified this type of MOLB to devise a new type facility called as T-MOLB.

At the thermal test, no degradation was confirmed at 25 cycle tests from 500? to 1,000? at warming rate of 100? /h. According to the report of Chubu Electric Power Co., a 15 kW T-MOLB type SOFC system was fabricated. That system has 3 trains and each train consist of 10 stacks which results to total 30 stacks, and each stack consists of 10 cells of 200mm2. Using this system they have already obtained the output of 15kW and confirmed no degradation even at the end of power generation operation for 1,000 hours.

PEFC for transportation application

Application of PEFC as a primary power source in electric vehicle has currently received rapidly growing attention. This attention has also been fueled with expectation of its feasibility as a residential co-generation system. Major automotive companies such as Toyota, Nissan, and Honda have succeeded in development of the fuel cell vehicles both fueled with methanol and hydrogen.

(1)Toyota Motor Co.

Toyota Motor Co. has already succeeded in the development of fuel cell powered electric vehicles both with pure hydrogen as a fuel or methanol reforming facility three years ago. A unique point in Toyota's fuel cell system for driving cars is that a hybrid structure in the power source is adopted with fuel cell and secondary battery. And it is capable of controlling their power sharing. In order to operate the power system at higher efficiency all the time, the control modes of power sharing between the fuel cell and the battery differs depending on the driving conditions. For example, the output power from the fuel cell is distributed to drive the motor at the normal driving condition, and the surplus power is stored into the battery. On the other hand, the motor is driven with powers from both the fuel cell and the battery at the high load region such as start-up and rapid acceleration. By using this hybrid system, about 10 to 30% of recovery energy generated at normal driving condition can be collected and recycled. This method results in a drastically improvement in a mileage of cars.

Another unique point is in using a metal hydride as a measure of hydrogen storage. The amount of hydrogen stored was improved up to 2.2 % in weight ratio but its value would still be too small to use as a fuel tank on board.

Various characteristics and performances of the fuel cell stack itself have also been improved based on the knowledge obtained in the past several years. As for the power density of fuel cell, the maximum output power of 70 kW could be obtained with a fuel cell stack of 65 lit. in volume and 75 kg in weight.

Executive Director Mr. Watanabe said "We want to bring fuel cell electric vehicle into the mass production in 2010" and have confidence on its commercialization".

(2)Nissan Automobile

Nissan Automobile presented the test vehicle with methanol reforming fuel cell system called R'nessa FCV. The PEFC stack with an internal humidifier as a power source for propulsion was provided by Ballard. Steam reforming method is applied to extract the pure hydrogen and palladium(Pd) hydrogen membrane is used to remove CO. And moreover high power density lithium ion battery is loaded on the vehicle to keep the recovered energy at the time of slow down and to deliver an enough energy to start up and accelerate the vehicle.

(3)Honda Motor Co.

Honda Motor Co. officially announced its fuel cell development efforts and exhibited two trial fuel cell vehicles called FCX-V1 and FCX-V2 at the Tokyo Motor Show. The FCX-V1 is driven with pure hydrogen and FCX-V2 keeps a methanol reforming device. The fuel cell stack was developed by Honda itself. The fuel cells were tested in various modes including the actual driving test, and the knowledge obtained from these test was reflected into the further development of the stack. The rated output of this fuel cell stack is 30kW, and great efforts are now devoted to further reduction on its size and weight. The reformer has also been tested in actual driving condition, which confirmed good transitional response time within a few seconds under the condition of even several 10 ppm of CO.

Honda participates with the newly developed fuel cell car called as FCX-V3 in the driving test on a public street which is being conducted under the California Fuel cell Partnership in Sacramento, CA, USA.

It is very important to discuss how the infrastructure is to be built for fuel delivery based on the choice of fuel for FCV. The argument on these problems is now proceeded under the leadership of METI.

<u>PEFC Development as Residential co-generation device</u>

Remarkable progress has recently been made in the field of PEFC which is expected to be available as a cogeneration device for residential use, because of its high power density, ordinary temperature operation, and potentially easy maintenance due to the simple structure.

(1)The Japan Gas Association

The Japan Gas Association has started its experimental demonstration project on the residential PEFC co-generation systems from February 1999 under the sponsorship of NEDO. Taking an averaged electric demand of households in Japan into consideration, the rated output power is basically selected to be 1 kW. In addition, the hot water of 60? is taken out from an exhaust heat. For design of cell stack, it is selected to operate at normal pressure for realizing the simplification of structure and reduction of auxiliary driving power. The water cooling system is adopted in order to recover the exhaust heat as a hot water. The steam reformer and cell off-gas recycle burner are adopted for the fuel reformer process to efficiently convert town gas into hydrogen. And the steam which is needed for the steam reforming is generated by sensible heat of reformed gas and burned gas of reformer.

The specification is showed in the figure.

Output Power ; 1 kW, 200V single phase, 3 lines, Grid connected operation
Exhaust Temperature; 60? , Fuel; Town gas 13A,
Operating Method and Structure; Automatic, and Package type,
Reformer; Absorbing desulfurization, Steam reforming,
CO Remover; Selective oxidization,
Working Pressure and temperature of PEFC; Normal pressure and about 80?
Cooling Method; water cooling
Capacity and Method of Power Converter; 1.2kVA and Current regulation

In addition, the Japan Gas Association has just started "The Stationary PEFC Millennium Project" That is a proof operation examination project being carried out by gathering several stationary PEFC residential co-generation systems. It will take 2000 to 2004, that is the 5 year plan, under the sponsorship of NEDO. The purpose of this project is to collect the data necessary for the establishment of examination method, safety standard, and other national standard. Proof operation will be examined on totally 11 units of PEFC. These units are in the output range from 0.2 to 3kW output units, and these are provided by Ebara-Ballard, Sanyo Electric Co., Toshiba, Matsushita Electric Industrial Co., Toyota Motor Corporation, H Power Corp, and Matsushita Electric Works. The Japan Gas Association is planning to proceed to the practical operation at real residences from FY of 2002, and then plans to make much efforts for its commercialization.

Toshiba

Toshiba Corporation has promoted a development of 30kW class PEFC system for a stationary co-generation as a part of NEDO project since 1999. Major efforts have been made to make it compact as a package of which sizes are 2.0m in width, 1.5m in depth, and 1.8m in height. It enable this system to put this package into a load elevator.

In addition to that, Toshiba has independently developed a 1 kW class PEFC system adaptable for a vending machine. PEFC supplies both the electricity and heat to a vending machine. This is very unique idea.

A traditional vending machine needs a cooling device which includes a compressor driven by electricity to chill the cans, and in addition needs a heater to warm the canes. This PEFC system produces electricity to drive the compressor and for light, and it also warms the canes by the heat exhausted from the fuel cell. In order to respond the load change and to supply electricity in starting up, a hybrid structure is adopted with a secondary battery. A propane gas as a fuel is stored in a cylinder. The fuel cell itself, the fuel treatment device, and the inverter/control devices are all so compact that all components can be put in a 1/3 of the whole bending machine.

This newly developed vending machine with PEFC has following advantages. First, it is high efficient because it can make good use of the heat exhausted by the fuel cell.

Secondly, it is available at un-electrified areas because of its codeless.

Matsushita Electric Industrial Co. has started its effort to develop PEFC in 1991. They are now accelerating the development of PEFC for a residential co-generation system. With respect to the cell stack, they devised several new ideas in its structure and materials to reduce the cost and size. For example, the metal separator was used, and the flow channel of each fluid such as hydrogen, air, and cooling medium were formed in the honeycomb and assembled to avoid useless space. The test of the cell stack using hydrogen/air showed a good property such as the output density of 1.2kW/Lit. with the current density of 0.8A/cm2.

A residential co-generation system requires such characteristics and performances as being highly efficient, small size, and maintenance free with the use of the natural gas or LPG as a fuel. Matsushita Electric Industry Co. has succeeded to develop a 1.5kW co-generation system for the domestic use with a size of 950mm in width, 320mm in depth, and 900mm in height. That is small enough to be installed under the eaves of the normal household.

Conclusion.

Although among major kinds of fuel cell system such as PAFC, MCFC, SOFC, and PEFC, PAFC is the only fuel cell being close to commercialization stage, it still needs large effort such as reducing the cost and exploiting the new market to reach at fully commercialization stage.

MCFC power plant has been under intensive development in Japan under the national project for the purpose of realizing it as a relatively large scale power plant combined with coal gasification and gas or steam turbine. The operational demonstration project of 1,000kW MCFC pilot plant with the external reformer and the 200kW plant with internal reformer were successfully completed by January 2000, and it is to be followed by the next phase of the national project.

SOFC is also expected to become a high efficient power plant in combination with coal gasification process, a gas turbine, or, and a steam turbine.

Major automotive companies succeed to develop and fabricate Fuel cell Vehicles using both hydrogen and methanol. There are, however, many difficulties to be overcome for the commercialization of FCV. Among them one of the most challenging problems seems to exist in the remarkable cost reduction of the fuel cell systems. Another important and strategic problem is supposed to be the deployment of infrastructure for fuel delivery to vehicles based on the choice of fuel.

The Japan Gas Association has been promoting the operational demonstration project on the PEFC co-generation system for the residential use in cooperation with major gas companies such as Tokyo, Osaka, and Toho gas under the sponsorship of NEDO.

I would like to conclude by saying the following remark.

In order to realize the commercialization of fuel cells, we still need to overcome many problems left behind. Among them, it seems to be the most important and challenging problem, in particular for transportation application, to manage the remarkable cost reduction. Assuring the reliability of fuel cell system is also very important.

In the circumstance of rapidly growing attention and expectation for the realization of fuel cells, many companies and institutions are now trying to participate in the fuel cell development fields from various directions. So it is impossible to describe the whole activities related to fuel cell development and deployment in Japan. I am afraid my presentation introduces only a part of these activities in Japan.

Thank you.